

REPRODUCE DIAMETER REDUCTION PROCESS OF A POWDER FILLED TUBE IN FINITE ELEMENT ANALYSIS

B. BÖCK^{*}, B. BUCHMAYR¹, S. WALLNER¹ AND G. POSCH²

^{*,1} Chair of Metalforming
Montanuniversitaet Leoben
Franz Josef Straße 18, 8700 Leoben, Austria
e-mail: barbara.boeck@unileoben.ac.at, web page: <http://www.metalforming.at>

² Böhler Schweißtechnik Austria GmbH
Böhler-Welding-Straße 1, 8605 Kapfenberg
e-mail: gerhard.posch@bsga.at, web page: <http://www.boehler-welding.at>

Key words: Roll Drawing, Reduction of a tube with powder filling, Powder Compaction,

Abstract. Aim of the present work is to improve the production of laserwelded flux cored wires with the help of Finite Element Analysis in Abaqus. This flux cored wires are used as welding consumables. To simulate the whole production process for every variety of input parameters is far too time-consuming particularly with regard to the filling. The production process is as following: after roll forming of a strip to a U-shape it is filled continuously with flux. This powder consists of up to 20 different substances. Afterwards the profile is closed to a tube and the edge is laserwelded. At last the diameter of the tube is reduced to 1.2 mm. The reduction step is investigated and subject of the present work. Observations have shown the most abrasion of the working dies in reduction steps where it is not expected due to the calculated true strain sequence. Therefore, the influence of the filling on the roll drawing process has to be taken into account. This is not easy because the process starts with loose multicomponent powder and ends with high compaction. It is hard to cover these demands with a single model for powder behaviour. So a phenomenological approach is established to solve the problem. The influence of the powder is described as a load which only appears in the projected contact area. Consequently, it becomes possible to study parameters on the reduction like different quantities of the multicomponent powder, the reduction sequence of the roll drawing process and the geometry of the rolls.

1 INTRODUCTION

Different powder models were studied to characterise the influence of the powder in the process. Soil mechanic models like Drucker-Prager/Cap describe lower compaction^[1]. Many models exists which handle the powder as a metal matrix with porosity, like Shima and Oyane or Gurson^[2]. These models are right at higher compaction^[3]. At last there are models which calculate the behaviour of spheres under pressure^[4,5]. This is far to time consuming for this kind of simulation. The production process leads to a high range in the compaction. Therefore one model could hardly reproduce the whole process. But it is impossible to fix a crossover

between two models. Furthermore all of them focus on the strength of the compacted powder and the density distribution during production to predict cracks in the finished parts. This is not relevant in this case. At least the experiments to characterise the powder are mostly very complex and expensive ^[6,7]. This is the reason why a phenomenological approach is added to the finite element analysis. A lot of investigational work has been done on characterisation of drawing process with axially symmetric dies ^[8,9,10]. The roll drawing process using roller dies is less studied ^[11,12,13]. All the researchers concentrate in their work on the reduction of rods or tubes with or without mandrel. The problem in the present work is that at the beginning loose powder is added. During the reduction process the multicomponent powder (flux) is compacted and acts as some kind of mandrel to the process. This is tightening up the investigation of the production process. Beside the pass schedule and the filling, the geometry of the rolls plays an important role. Also the strain-hardening of the tube has to be considered. These parameters are interacting in the roll drawing process that's why it is difficult to handle in the finite element analysis.

2 ROLL DRAWING

Metallographic specimens show the influence of the used amount of multicomponent powder. Due to varying bulk volumes the wall thickness in the final cross section differs. If there is no powder added the inner diameter vanish. Three examples are shown in Figure 1. The outer diameter stays the same.

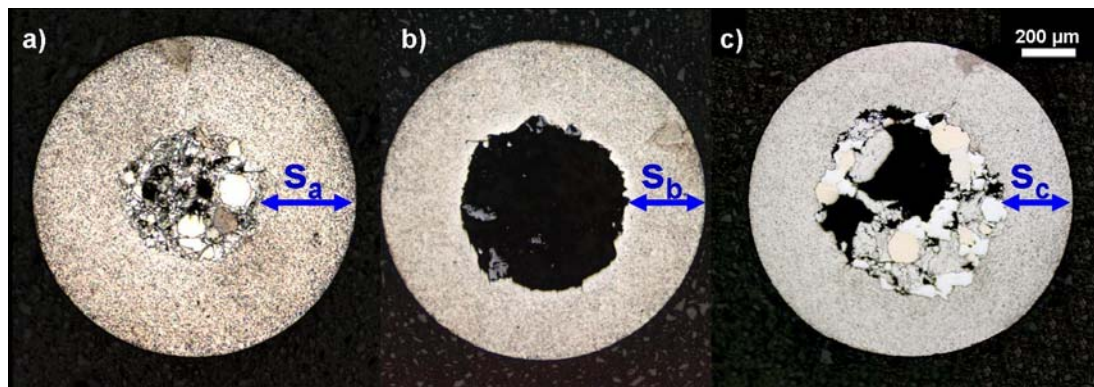


Figure 1: Cross section through the final product for three different filling volumes (increasing from a to c), outer diameter 1.2 mm

The wall thickness is measured in three different positions, because the inner outline is very rough. The mean is build as shown in Table 1.

Table 1: Measured and Mean Wall Thickness

Sample ID	Measured Value [μm]			Mean [μm]
s _a	232	339	338	333
s _b	264	289	233	262
s _c	225	251	245	240

For the shown cross sections an axial elongation can be calculated, which reaches from 12 up to 15. This leads to the assumption of an equilibrium between the compaction of the multicomponent powder, the reduction of the roll drawing process and the strain-hardening of the strip metal. These parameters influence the outcoming wall thickness.

The strain-hardening of the outer strip material was determined with tensile tests. The extended formula of Ludwik^[14] is used to calculate the flow stress (k_f) for the deformed outer tube in every specific sequence of the reduction process.

$$k_f = k_{fA} + B\varphi^n \quad (1)$$

The function is defined as following: k_f is the true stress, k_{fA} is the yield strength at $\varphi=0$, B is the yield strength at $\varphi=1$, n is the strain hardening exponent, φ is the true strain. An ideal plastic strain is defined by the sequence of the process. This is set as initial condition to the model to consider the hardening of the outer strip metal.

3 INFLUENCE OF THE POWDER COMPACTION

The compaction behaviour is studied with an isostatic press. Different equiaxed loads are applied on a weighted mass of the multicomponent powder in a rubber mould and the volume is detected. From the results the relative density under pressure is recorded. The compaction behaviour depends on many parameters like chemical composition, additives, particle size, particle shape and the mechanical properties of the full material^[15,16,17]. Therefore the graph shown in Figure 2 is only valid for this special composition.

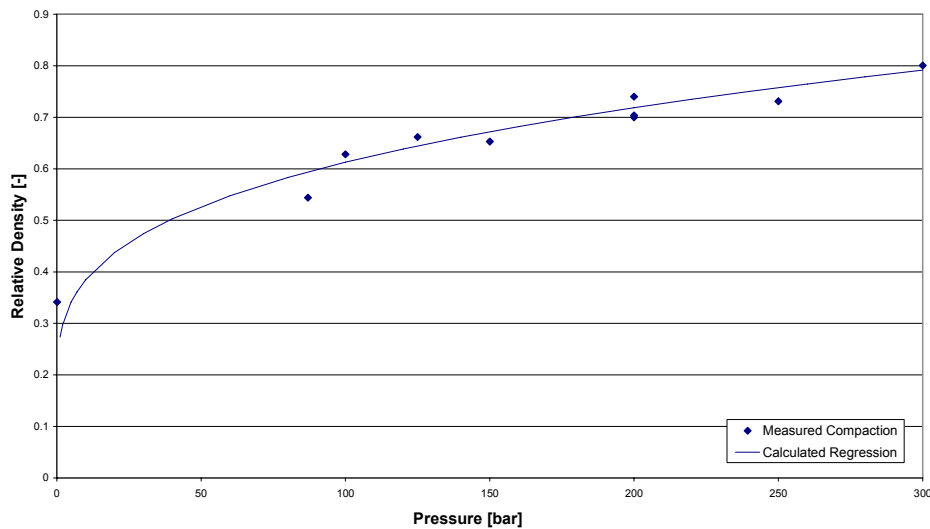


Figure 2: Measured Compaction and the Calculated Regression of the powder filling

The compaction behaviour of the multicomponent powder is expressed mathematically. Literature gives correlations between powder compaction and surrounding pressure. For example Schatt^[15] defines the pressure which is needed to compact the powder until no porosity is left (p_{max}).

$$p_{\max} = p \left(\frac{1}{\rho_{\text{rel}}} \right)^m \quad (2)$$

For cylindrical specimen can be calculated ^[16]

$$F = \int_0^{r_i} 2r\pi\sigma_z dr \quad (3)$$

where σ_z is

$$\sigma_z = \bar{\sigma} \exp \left[\frac{2\mu_i}{L}(r_f - r) \right] \quad (4)$$

$$\bar{\sigma} = k_f \left(\frac{1 + \mu_i}{1 - \mu_i} \right)$$

μ_i is set for the inner friction between the particles. r is the specimen radius. p stands for the pressure. ρ_{rel} is the relative density. σ are stress components (z direction and mean stress). k_f is the yield strength of the powder as full material. m is the compaction exponent. A potential function is used to express the compaction of the powder. So it is valid to use a similar function to calculate the regression for the powder compaction (Figure 2).

$$\rho_{\text{rel}} = \rho_b + B\phi^m \quad (5)$$

ρ_b stands for the bulk density of the powder. B is a factor which is adjusted to the compaction behaviour. This formula is used to calculate different quantities of the filling. From this the behaviour of any bulk volume under pressure can be calculated. The limits are given by the production process. Figure 3 shows an example for the correlation between volume and pressure for three different quantities of the multicomponent powder.

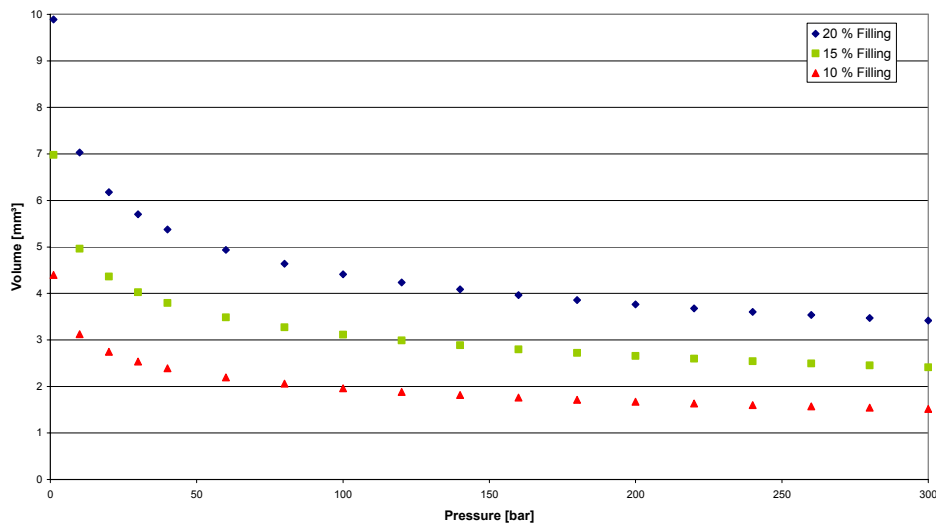


Figure 3: Different quantities of powder under pressure

After each roller die package a cross section was taken to measure the inner and outer diameter of the tube. The area is calculated and multiplied with the elongation of the tube. This leads to the actual volume. Now a pressure which is needed to compact the multicomponent powder to this level can be assigned to the inner volume. So, a value for the inner pressure as a result of the powder compaction is found and added to the finite element analysis. Of course, the relationship of the inner and outer diameter is influenced by the quantity of the powder and its compaction. But as a compromise this is neglected and the inner volume is taken absolut.

To fix the region in which the compaction of the powder lead to a pressure on the inner wall a finite element analysis has been started. The projected contact area is a far to rough estimate. A very soft material is taken instead of powder. The geometry is authentic to the production process. A region could be fixed following the stress distribution in a cut of the finite element analysis shown in Figure 4.

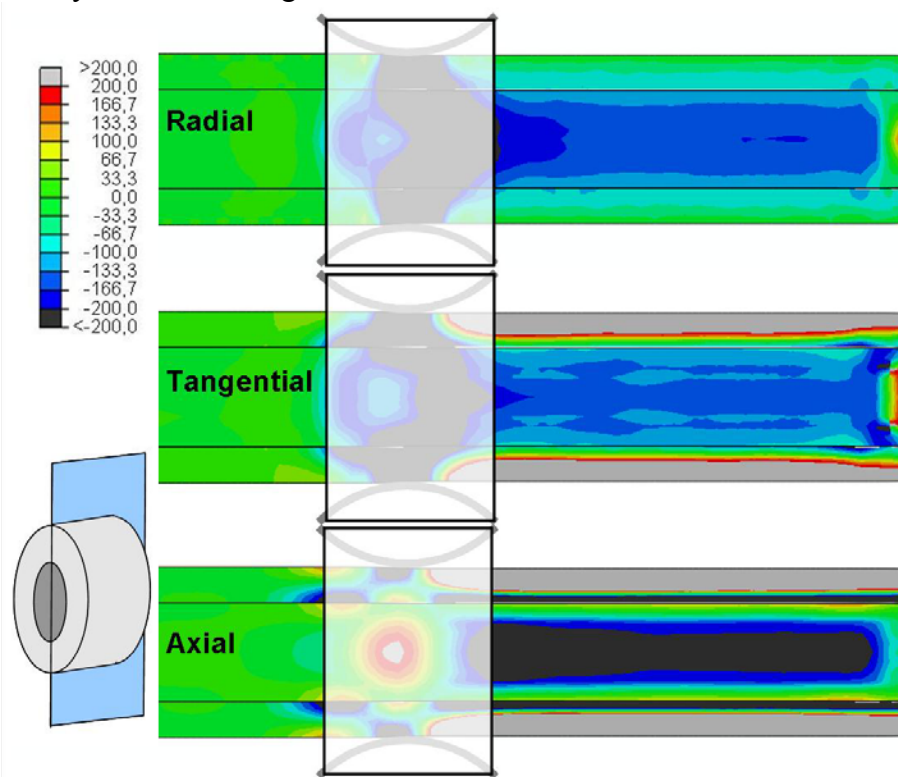


Figure 4: Cut through the tube in the FEA with the stress distribution for the principal directions

A few differences have to be considered between deformation of a soft full material and a powder. At first no tension can occur in powders like the axial stress distribution shows. A far smaller elastic springback appears in compacted powder. The contact area for friction is much higher between a rod and a surrounding tube. The powder does not compact under shear stresses, whereas full materials can yield. This is why this analysis is only valid for finding the region for backpressure and could not be a simplification for the whole process.

4 FEA MODEL

For the first simulated roller die the tube is considered as a stress and strain free material. On later roller dies a strain-hardening is added. The influence of the multicomponent powder is included through a user defined subroutine. The load only appears in the roller dies. The tube between the roller dies is unaffected which agrees with reality. The welding seam is included in the tube geometry and carries a separate material property due to the laser welding process. A package with twelve roller dies is always simulated at once. Two dies have always the same geometry. They alternate between horizontal and vertical positions. Abaqus Explicit is used, with C3D8 elements. The outer strip is made out of a soft steel with low strength. In the welding seam a modified material property is installed, due to the rapid cooling in the laser welding process. Roll drawing is a cold forming process. Between the roller dies and the tube rolling friction appears. As a result not much heat occurs. That's why the heat is neglected in the finite element analysis. Figure 5 show the start of the finite element analysis with the tube in front and the alternating roller dies in the back.

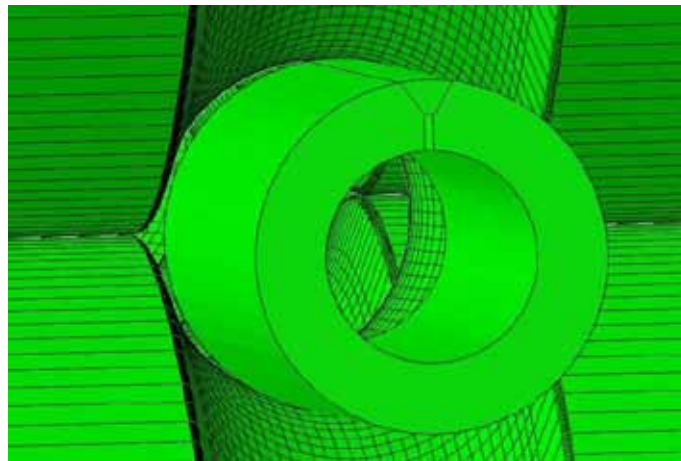


Figure 5: FEA model of the roll drawing process

Figure 6 shows the radial stresses due to the load of the powder defined in the user defined subroutine. This picture is taken from an analysis with no rolls to control the input.

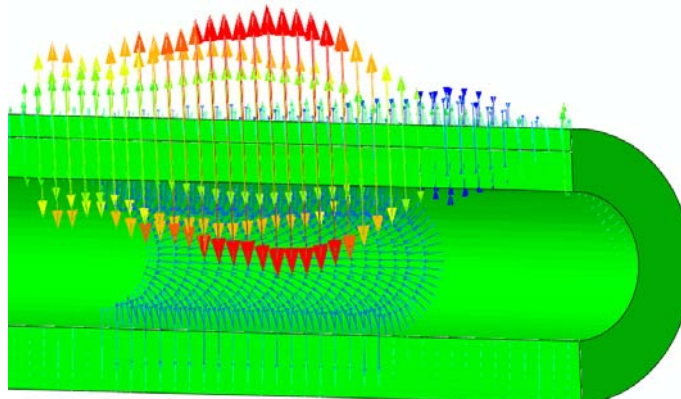


Figure 6: Stresses due to VDLload

5 RESULTS

Figure 7 shows the equivalent stress and the principal stresses for the first roller die. The upper roll which is identical to the lower is hidden to get a free view on the welding seam. The ovality occurs due to the spread. The geometry of the rolls itself is round and ends in 40° tangents. Between 40° and 50° is common for pass design.

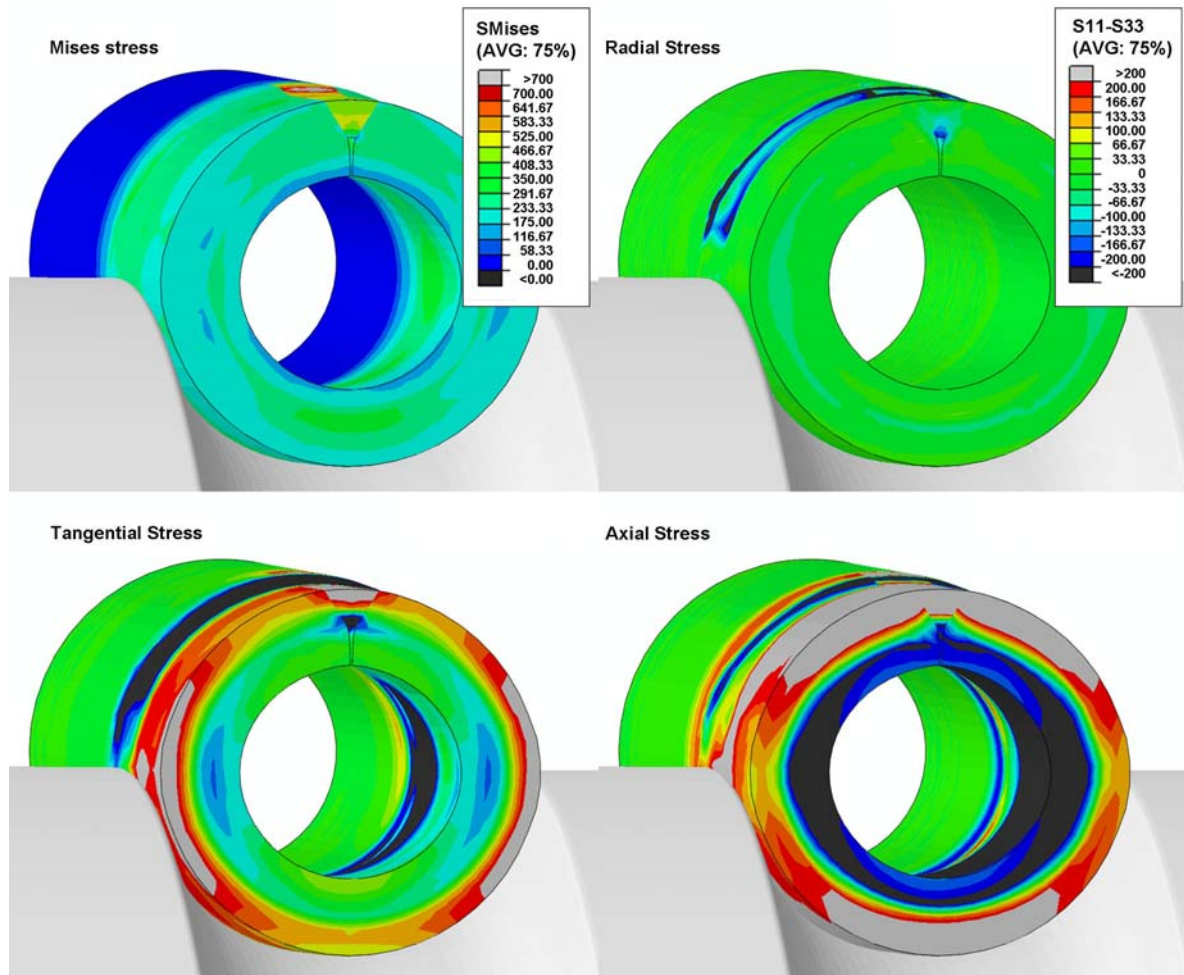


Figure 7: First Roller Die with inner pressure, upper roll is removed, Mises and principal stresses

6 CONCLUSION

The discussed procedures allows to simulate the complex relationship in this production. The model show good correlation to reality which proves its validity. Specific sequences can be picked out to study the parameters like roll geometry, process variables and the reduction sequence. The reactions of the system as there are out-of-roundness, stress and strain distribution and twisting can be determined. Furthermore the Finite Element Analysis runs at reasonable computing times.

ACKNOWLEDGEMENT

Financial support by the Austrian Federal Government (in particular from the Bundesministerium für Verkehr, Innovation und Technologie and the Bundesministerium für Wirtschaft und Arbeit) and the Styrian Provincial Government, represented by Österreichische Forschungsförderungsgesellschaft mbH and by Steirische Wirtschaftsförderungsgesellschaft mbH, within the research activities of the K2 Competence Centre on “Integrated Research in Materials, Processing and Product Engineering”, operated by the Materials Center Leoben Forschung GmbH in the framework of the Austrian COMET Competence Centre Programme, is gratefully acknowledged.

REFERENCES

- [1] Coube, O. Modellierung von Verdichtung und Rißbildung beim Trockenpressen von Metallpulvern, *Symposium 14: Simulation Metalle*, Werkstoffwoche 98, Wiley-VCH, Weinheim, 1999
- [2] Parteder E. *Ein Modell zur Simulation von Umformprozessen pulvermetallurgisch hergestellter hochschmelzender Metalle*, Umformt. Schriften V. 94, Shaker Verlag, 2000
- [3] Lorenz B. *Ein Beitrag zur Theorie der Umformung pulvermetallurgischer Anfangsformen*, Habilitation, TU Freiberg, 1996
- [4] Martin, C.L. Elasticity, fracture and yielding of cold compacted metal powders, *Journal of Mechanics and Physics of Solids* (2004) **52** 1691-1717,
- [5] Sinka I.C., Cocks, A.C.F. Constitutive modeling of powder compaction I+II, *Mechanics of Materials* (2007) **39** 392-403
- [6] Rottmann G. Mechanisches Verhalten beim Trockenpressen, *Doctoral thesis*, University of Karlsruhe (2001)
- [7] Chtourou H., Guillot M., Gakwaya A. Modeling of the metal powder compaction process using the cap model. Part I, *Int. Journal of Solids and Structures* (2002) **39** 1059-1075
- [8] Kröff A. Numerische Untersuchung und Optimierung des Ziehens von hoch kohlenstoffhaltigen Stahldrähten, *Doctoral thesis*, University of Hannover (2001)
- [9] Gummert H.-J. *Ziehen*, (2005), F&S Druck, Hundsmühlen, ISBN 3-00-016406-5
- [10] Funke P. *Ziehen von Drähten, Stangen und Rohren* (1987), ISBN 3-88355-124-4
- [11] Jaschke D. Untersuchung zum Ziehwalzen von Drähten und Profilen aus metallischen Werkstoffen, *Doctoral thesis*, University of Clausthal (1976)
- [12] Överstam H. The influence of bearing geometry on the residual stress state in cold drawn wire, *Journal of Material Processing Technology* (2006) **171** 446-450
- [13] Murakawa M. Masahiko J. Hayashi M., Study on semidry/dry wire drawing using DLC coated dies, *Surface and Coating Technology* (2004) **177** 631-637
- [14] Hensel A., Spittel T. *Kraft und Arbeitsbedarf bildsamer Formgebungsverfahren* (1978) VEB, Leipzig ISBN 152-915/74/78
- [15] Schatt W., Wieters K.-P., Kieback B. *Pulvermetallurgie* (2007), Springer Verlag, Berlin ISBN 3-540-23652-X
- [16] Al-Qureshi H.A., Galiotto A., Klein A.N. On the mechanics of cold die compaction for powder metallurgy, *Journal of Materials Processing Technology* (2005) **166** 135-146
- [17] Lee S.C., Kim K.T. A densification model for powder materials under cold isostatic pressing, *Materials Science and Engineering* (2008) **A 498**, 359-368